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CLOSING THE GAP:
AN ANALYSIS OF OPTIONS FOR IMPROVING THE USAF FIGHTER FLEET FROM 2105 TO 2035

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ABSTRACT

The “fighter gap” refers to a shortage of fighter aircraft inventory or capacity. Due to budget concerns, procurement numbers for 5th generation fighters are falling, and legacy fighters are reaching the end of their service life and retiring. The result is a shortage in both fighter aircraft quantities and in capacity for delivering weapons from fighter platforms. The criteria of lethality and survivability, cost, and the need for 4th and 5th generation capabilities are examined and used as the basis of comparison between 3 alternative solutions provided by the Congressional Budget Office. This examination reveals that potential advantages in range, payload, standoff, and cost make enhanced legacy fighters the most suitable option for closing the fighter gap. Two enhanced legacy fighters, the F-16E and F-15SA, are compared to reveal that the F-15SA provides the most significant increase in capacity and capabilities to the USAF fighter inventory. Finally, this study concludes with the recommendation to purchase 200 enhanced legacy fighters such as the F-15SA.

INTRODUCTION

For just over a century, aircraft have been providing military forces with devastating potential on the battlefield. From war torn Europe to Afghanistan and Iraq, the fighter has proven its worth and versatility as a weapons system. The introduction of 5th generation fighter aircraft such as the F-22 Raptor and F-35 Lightning II has revealed capabilities that are likely beyond the dreams of the pioneers of flight. Advanced flight capabilities, stealth technology, and improved sensors lead to a level of lethality and survivability unheard of in previous designs.

The benefits of these newest fighters do not come without cost. The complexity of these systems, driven largely by the stealth technology, has reportedly driven the cost of these aircrafts to levels that garner sharp attention (and often criticism) from congressional leaders and media figures. These rising levels of development and procurement costs come at a time when military spending is falling dramatically, and every decision to acquire one new weapons system could prevent or delay the acquisition of another that is deemed necessary.

The fiscal demand of advanced fighters is coupled with the reality that our existing fleet of 4th generation fighters, having been proven on the battlefield for the last 20 years, is nearing the end of its life expectancy. Older fighter platforms are retiring soon, and new fighter platforms are being procured in smaller numbers than the Air Force had requested. The result is a pending "fighter gap:" a shortage of fighter airframes and fighter capabilities spanning from 2015 to approximately 2035.[1] Long term acquisition plans are already in motion that will make the F-35 and F-22 the mainstay of the fighter fleet, but the potential for too few aircraft or a capabilities shortfall may require augmentation by aging 4th generation fighters or a suitable substitute.

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Research Question

This paper strives to answer the following question: Which of the three alternative fighter acquisitions plans offered by the Congressional Budget Office is best for filling the fighter gap? The goal of this research is to determine the most advantageous fighter procurement alternative in terms of maximizing capacity while minimizing costs.

This research will employ the problem/solution framework. First, the factors that have led to the fighter gap will be reviewed. Understanding the factors that have contributed to the current shortage may be useful in determining the best solution.

Next, this study will examine several alternatives for solving the fighter gap as proposed by the Congressional Budget Office.[2] While the CBO offers a variety of solutions, including the use of UAVs or other platforms, this study will focus on fighter platforms as the preferred solution due to the assumption that the Air Force's fighter requirements can only be met by platforms that possess capabilities unique to a fighter. Other alternatives are beyond the scope of this study. This study aims to examine the capabilities, cost, and necessity of, legacy, enhanced legacy, and 5th generation fighters. It will then apply those criteria in a comparison of the CBO's alternatives and make a recommendation on which solution is best.

Capabilities will be further broken down into the two basic components of lethality and survivability. Necessity will involve a discussion of scenario employment, ranging from the continued use of fighters as an uncontested close air support (CAS) platform to full scale combat against a near peer adversary in an anti-access/area denial (A2/AD) environment. This discussion will illustrate the capabilities and attributes that are required for successful fighter

employment is such a scenario. The alternatives will then be compared using the criteria and recommendations will be offered.

Significance

In light of the growing costs of fighter aircraft, RAND Corporation has suggested that the services improve their processes for defining aircraft requirements.[3] Given the financial restraints of the DoD, and the growing costs of developing, acquiring, and sustaining fighter aircraft, it is imperative that policy makers have a clear understanding of the true fighter requirements along with the costs and benefits of each. This study will strengthen that understanding and build a working knowledge of fighter characteristics and capabilities. This research will conclude with a recommendation for filling the fighter gap that will maximize capabilities while minimizing additional investments.

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BACKGROUND

At the time of the air campaign in Iraq in 1991, the US Air Force inventory included approximately 3,500 fighter and attack aircraft. This included at least 9 distinct airframes performing the fighter or attack role across the Department of Defense. The retirement of aging platforms such as the F-4 and F-111 left a fleet with an average age of only 8.5 years per airframe[4] consisting of F-15s, F-16s, and A-10s.

These aircraft now represent the bulk of our Air Force fighter inventory and average over 20 years old. While some of these aircraft are expected to serve nearly 40 years, this represents a significant shift from the USAF policy of the 1990's for retiring fighters after 22 years of service.[5] Many of these aircraft, including the F-16 and F-15E, are undergoing life extension programs in order to maximize length of service, though these measures are costly.

Many 4th generation fighters, such as the F-15C/D and F-16, are nearing their life expectancy.

In 1992, planning had begun for modernizing the fighter fleet and maintaining technological superiority for decades to come. The earliest program for the Air Force was the Advanced Tactical Fighter (ATF) that sought to replace the F-15A –D models. This air superiority fighter was to incorporate reduced radar cross section (RCS), otherwise known as stealth or Low Observable (LO) technology, as well as superior flight performance and avionics integration.

The Air Force and Navy also undertook joint planning for a Medium Attack Aircraft (AX). This was an LO platform with moderate air to air ability intended carry a large number and variety of air to ground munitions over relatively long distances. The AX was a planned replacement for the F-117, F-111, F-15E and Navy A-6.[6]

Proposals were also made for development of the Multi-Role Fighter (MRF). This was to mimic the success of the "high/low" employment concept of the F-15 and F-16, in which the former was a relatively expensive air superiority fighter, and the latter was a cheaper multi-role platform purchased in higher numbers.[7] The MRF was intended to incorporate some reduction in RCS while maintaining an air to air capability, but would be acceptably less capable than the ATF in order to keep costs relatively low. The MRF would then be produced in high numbers to replace the F-16 as a compliment to the more capable ATF.[8] Direct replacements for the A-10 or USMC AV-8 attack aircraft were not specified among these programs.

Actual development and procurement of these programs did not occur as depicted in the 1992 DoD budget proposals. The ATF matured into the F-22 program,[9] and the proposed procurement levels were reduced from 750 total F-22s in 1991, to only 183 F-22s purchased prior to shutting down the production line in 2012.[10]

In addition to F-22 cuts, the AX has disappeared entirely. The Navy opted instead for the F/A-18E/F in place of both the AX and Navy ATF. The Air Force had considered procuring up

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to 400 aircraft such as the F-22B, a larger version of the F-22 intended primarily for air to ground attack, but the program was not pursued.[11] Currently there are no programs specifically intended to replace F-111, F-117, or F-15E.

The DoD has invested heavily in the MRF instead. Now the F-35 or Joint Strike Fighter (JSF), it is intended to be the sole 5th generation compliment to the F-22 through 2035 and will replace every other legacy (or 4th generation) fighter. This includes the A-10, F-18A-D, and AV-8. This is in contrast to the original intent of the platform, in which it would replace only the F-16. While the Air Force intended to hold down the cost of the Multi Role Fighter in order to purchase greater numbers,[12] the Joint Strike Fighter has grown into the largest weapons system procurement in the DoD.[13] The DoD has reduced the overall procurement by over 400 aircraft, and deferred the purchase of an additional 400 aircraft until after 2017.[14]

Reductions and deferrals of 5th generation procurements have left these fighters operating alongside the legacy aircraft they were intended to replace. As the legacy force begins to retire in or shortly after 2015, and until a full complement of F-35s is available in 2035, the total number of fighters may fall below the minimum required by the USAF. This shortage is referred to as a fighter gap.

The 2009 Congressional Budget Office (CBO) report predicted that the fighter inventory would fall below the desired level of 2,200 fighters in approximately 2015. It indicated this shortage would peak in 2025 with a shortage of 400 aircraft, or 20% of the desired number.[15] A DoD report in 2013 supports the initial shortage, indicating only 1972 fighters in that year (excluding the Air National Guard). Deferments of JSF purchases will compound the issue in earlier years,[16] while the retirement of legacy fighters will fluctuate slightly from predictions.

As stated in a 2013 DoD report to Congress, one of the major DoD investment objectives is to "acquire fifth-generation fighter/attack aircraft while maintaining sufficient inventory capacity."[17] The CBO recognizes a shortfall in capacity, measured in total capabilities, and the number of air to air and air to ground weapons fighters can deliver to the battlefield.[18] Based on these considerations, the CBO offered 7 alternative plans for ensuring minimum fighter capacity was met until 2035. While these alternatives included the use of bombers and UAVs to supplement fighter operations, this study will focus only on the 3 alternatives that rely on the use of fighter aircraft only:[19]

1. Satisfy Inventory Requirements by Accelerating and Increasing Purchases of JSFs by 164 aircraft
2. Satisfy Inventory Requirements by Purchasing 270 Fewer JSFs and Purchasing 435 Improved Legacy Aircraft
3. Cancel the JSF Program and Satisfy Inventory Requirements by Purchasing 1925 Improved Legacy Aircraft

ANALYSIS

The first step in comparing these alternatives is understanding the differences in the existing airframes. According to the USAF Scientific Advisory Board, 4th generation fighters are defined as those fighters built in the 1980s, utilizing 1970s design concepts. On the other hand, 5th generation fighters "are characterized by being designed from the start to operate in a network-centric combat environment and to feature extremely low, all-aspect, multi-spectral signatures employing advanced materials and shaping techniques."[20] They also possess actively scanned array (AESA) radars with large bandwidth and low probability of intercept. For the purposes of this study, 5th generation aircraft will be those that incorporate low RCS (radar cross section) from design. 4th generation fighters that have been upgraded with attributes such as AESA

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radars, post-design RCS reduction, or improved avionics are considered enhanced legacy fighters. An example would be the Navy F/A-18E/F.

While the details of 5^{th} generation fighter capabilities are not publicly releasable, the characterization of their performance is profound. In 2006, Lockheed Martin Vice President George Standridge stated the F-22 and F-35 "bring an order of magnitude increase in capability, survivability and supportability over legacy fighters, at a significantly lower cost and will transform defense worldwide."[21] He added that the F-22 is 3 times more capable than the F-15, while the F-35 is four times more effective than legacy fighters in air-to-air engagements and eight times more engaging fixed and mobile ground targets.[22] While some specifics of these claims cannot be verified at an unclassified level, a basic comparison can be made between 4^{th} gen, 5^{th} gen, and enhanced legacy fighters. As fighter aircraft strive for the ability to achieve the first look, first shot, and first kill in any air to air engagement, lethality will be considered primarily in the Beyond Visual Range employment. First look, first shot, first kill also indicates the importance of lethality in the air to ground role, and will be paired with survivability, cost, and need for each generation (legacy, enhanced legacy, and 5^{th} generation) of fighter for analysis.

The first comparison will involve lethality and survivability. These two factors combine for a single point of comparison, as a fighter that is not survivable may not last long enough in an engagement to deliver ordnance. Likewise, a fighter that is survivable but lacks lethality may not provide sufficient effects on the battlefield despite surviving the engagement. Often, the same factors that lead to survivability will enhance lethality, and vice versa.

5^{th} gen fighters combine "stealth, super-cruise, maneuverability, and many other features that enable the first-look, first-shot, first-kill capability."[23] This first look/shot/kill capability is

enabled first by aircraft flight performance. The chart below provides a comparison of aircraft weight, thrust, and potential speed for the F-22, the F-35, and the 4th gen aircraft they were designed to replace.

Table 1. Basic Fighter Performance Data

	Aircraft weight with internal fuel	Total thrust available	Max ceiling	Max airspeed
F-15C	44,000 lbs	47,000lbs	65,000 ft	Mach 2.0+
F-16C/D	26,700 lbs	27, 000 lbs	50,000+ ft	Mach 2.0
F-22	61,000 lbs	70,000 lbs[note 1]	50,000+ ft	Mach 2.0+
F-35A	47,500 lbs	43, 000 lbs	50, 000+ ft	Mach 1.6

Adapted from: United States Air Force. *USAF Fact Sheets.* 2015. http://www.af.mil/AboutUs/FactSheets
F-35A weight from: "Lightning Rod: F-35 Fighter Family Capabilities and Controversies" *Defense Industry Daily* 2015 http://www.defenseindustrydaily.com/lightning-rod-f-35-fighter-family-capabilities-and-controversies-021922/

Note 1: approximated based on engine class

The figures above illustrate several points. While exact performance is not reported, the significantly higher thrust to weight ratio of the F-22 results in higher altitudes and higher airspeeds, resulting in a more kinetic energy available for air to air and air to ground weapons, which in turn increases the range at which they can be employed.[24] This is one contributing factor in achieving the first look, first shot (or First Launch Opportunity – FLO), first kill advantage that the USAF seeks to achieve with 5th gen fighters.

Additionally, the F-22 is the only US fighter which employs thrust vectoring. Along with the increased thrust, the thrust vectoring allows for extreme nose authority in a turning fight, giving the F-22 a distinct advantage in maneuverability over other aircraft. The advantage in speed, ceiling, and maneuverability allow the F-22 to place itself in a position of offensive advantage and also to defeat or disengage from potential threats with greater ease than its 4th gen predecessors.

While speed, altitude, and maneuverability have typically been recognized as a desirable quality for fighters, they are not necessarily 5th generation attributes. This is demonstrated in

Table 1, in which the F-35 has a thrust to weight ratio, top speed, and max service ceiling that closely match the legacy fighters.   This results in flight performance that “merely” matches, if not lags behind, the performance of an F-16 or F-15. This has led to significant criticism of the F-35 as a follow on to the F-22 in the media and public forums.[25]

While the performance factors described above are traditionally recognized as vital fighter attributes, there is significant evidence that the most critical factor is situational awareness (SA).[26] Aerial combat can be defined as “a dynamic competition for SA,” in which the side with the most SA usually becomes the victor.[27] SA is the ability to recognize and process what is happening, and is provided to the pilot or operator largely via sensors. Those sensors include primarily the radar, Infra-Red sensors (IR), passive sensors, or event the eyes of the aircrew. In the realm of beyond visual range aerial combat, the most important of these is the radar.

4th generation fighters have effectively utilized mechanically scanned radars in air to air and air to ground targeting for decades. Limitations inherent to these radars, have led to the procurement of AESA radars. In simple terms, AESA radars utilize multiple beams from a single aperture to provide enhanced multiple target tracking and targeting, improved scan volumes, better resistance to electronic attack (EA; jamming), and Low Probability of Intercept (LPI).[28] AESA radars also enhance resolution and accuracy of air to ground radar maps for improved targeting of air to ground weapons.[29] The F-22 and F-35 have incorporated the APG-77 and APG 81 AESA radars, respectively. Each is also reported to support LO with reduced RCS of the aperture itself.[30]

Many 4th generation fighters (the F-15C, F-15E, and some versions of the F-16) are currently being upgraded employ AESA radars.[31] At first glance, these upgrades give 4th generation

fighters the same ability to target via radar as the F-22 or F-35. This notion fails to account for sensor fusion.

In addition to the radar, some fighters employ IR sensors such as Infra Red Search and Track (IRST). While many 4th generation fighters employ or can be upgraded to employ IR sensors, as is done with enhanced legacy fighters, the key difference between 4th and 5th generation fighters is the integration of information from all available sources. As stated by one pilot, "In the Raptor, the data is already fused into information thereby providing the situational awareness… There's virtually no data in the F-22 that you have to process; it's almost all information."[32]

This sensor fusion is a key aspect of the F-35. Its revolutionary Electro-Optical Distributed Aperture System (DAS) provides 360 degree SA, creating an airframe that "sees completely around itself."[33] This is paired with a radar that is essentially a multi function array for targeting, passive detection, and EA and an Electro-Optical Targeting System (EOTS). These systems work synergistically to provide and fuse "the kind of information that was previously only available…in the CAOC."[34] This clear advantage of enhanced SA for 5th gen fighters is a major contributor to the intent of achieving the first look, first shot, first kill mentality, and arguably compensates for the F-35s questionable flight performance as compared to the F-22.

One of the initial enablers of the "first look/shot/kill" approach is the addition of LO technology. This feature is not found on 4th generational fighters. While limited reductions of RCS could theoretically be implemented in 4th gen upgrades, those improvements are costly and far less effective than the low RCS designs of 5th gen platforms. Aircraft shape affects RCS more than the size of the aircraft or use of Radar Absorbent Material (RAM), ensuring that RCS reduction in legacy fighters would either involve major structural alteration or be doomed to mediocre improvement.[35]

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If SA is indeed the key to aerial victory, the advantage of LO is the complete denial of SA for the enemy (assuming that detection is denied entirely). The more likely effect of LO is to delay acquisition or deny targeting of the aircraft by an adversary. This enables the LO fighter to detect, target, and kill a threat while denying the adversary's awareness or ability to effectively engage the fighter, which enhances both lethality and survivability.[36]

Though LO design of 5th generation fighters is effective against enemy radar, these platforms are still potentially susceptible to IR detection, passive detection of RF emissions (like the use of own-ship radar), and visual detection. Additionally, a multitude of advanced techniques are being developed for detecting and targeting LO platforms.[37] Moreover, maintaining a low RCS requires carriage of non stealthy weapons in internal bays, reducing armament carriage capabilities. This also potentially reduces the range of the aircraft. Maneuverability may be affected by LO design, though the F-22 demonstrates that this is not a certain drawback for current or future LO platforms. Finally, the most significant limitation of LO may be the cost of design and procurement. Both weapons carriage and cost will be discussed in greater detail in a later section.

In addition to LO, a fighter can enhance survivability and lethality through the use of Electronic Attack, or EA. EA is like LO in that it delays or denies detection and engagement by radar. Legacy fighters have employed EA in a variety of ways with great effect since they become operational decades ago. Self protection jammers (jammers that are on board the fighter) are used to deny targeting or to produce sufficient miss distances to enable the fighter's survival of the engagement.[38] Miss distance, the distance between the point of missile detonation and its intended target, can be further enhanced through the employment of a towed decoy.[39] As miss distance grows, so do the fighter's chances of surviving the engagement. The

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enhancement to survivability is clear, but self protection EA can also enhance lethality by delaying an enemy's targeting until the fighter has ensured first launch opportunity.

EA can be employed using a variety of techniques. A common technique among legacy fighters is noise jamming, which is an attempt to saturate an enemy radar with random radio frequency (RF) energy.[40] This technique requires the jamming signal to be equal to or stronger than the fighters radar return when it arrives at the victim radar. The radar return gets stronger with higher victim radar power (gain), shorter range from the fighter to the victim radar, or larger fighter RCS. The jamming signal must be sufficient to raise the victim radar's noise threshold to a level higher than the radar return, resulting in a signal to interference ratio less than 1.0, in order to deny detection. This does not require the jammer to have a higher power than the victim radar, as the range covered by the jamming signal (fighter to victim radar) is half that of the radar signal itself (victim radar to fighter, back to radar). The effects of this process are illustrated in the graph below.

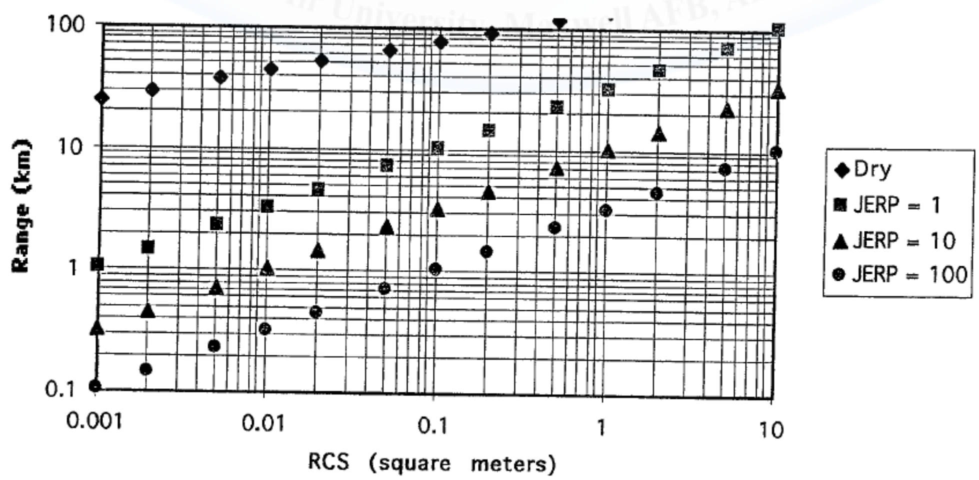

Figure 1. Detection Range versus RCS and Jamming (Brian M Flachsbart,. *A Robust Methodology to Evaluate Aircraft Survivability Enhancement Due to Combined Signature Reduction and Onboard Electronic Attack.* Post Graduate Thesis, [Monterey CA, Naval Post Graduate School, 1997], 15)

This graph depicts the notional detection range of a US fighter by a MiG-29 for a given RCS or Jammer Effective Radiated Power (JERP), measured in watts.[41] It is important to note that

modern self protection jammers are capable of producing up to several thousand watts of JERP.[42]

This demonstrates that in this notional scenario, a fighter with an RCS of 1m^2 and no jamming will be detected at over 100km, while just 10 watts of JERP will delay detection until just inside of 10nm. A comparison can be made using unclassified RCS approximations for today's fighters. The chart below assumes internal carriage, or stealthy configuration, for the F-22 and F-35.

Table 2. RCS By Airframe

AIRFRAME	F-15C/E	F-16C	F-22	F-35A
RCS (m^2)	10-25	2-5	.0001	.0005
RCS (dBsm)	11	5	-40	-35

Adapted from: Jeremiah Gertler, *Air Force F-22 Fighter Program*, (Washington DC: Congressional Research Service, 2013) 4 and Serdar Cadirci, *RF Stealth (or Low Observable) and Counter-RF Stealth Technologies: Implications of Counter-RF Stealth Solutions for Turkish Air Force.* Thesis, Naval Post Graduate School, 2009, pg 43

The fifth generation fighters are not likely to be detected at any range prior to visual detection by a radar utilizing the parameters in figure 2. An F-16 sized fighter may avoid detection using only modest levels of jamming power. A larger airframe like the F-15 may require much higher level of JERP, particularly when carrying large external stores that push its RCS to the higher end of the range given in the table. It is important to note that the parameters used in this scenario are simply a representation of one possible air to air threat, and more advanced air to air radars can yield significant differences. Surface to air threats likely require a much higher level of JERP due to the higher peak and average power as well as the larger aperture, or radar antenna size, associated with those threats.[43]

It is likely that for certain threats a large RCS fighter will not be able to produce the JERP necessary to deny detection. In this case, a fighter may employ deception jamming or utilize the support of a standoff jammer. Deception jamming is often referred to as repeater jamming, as it attempts to mimic the threat radars parameters and introduce errors and false data. Many

methods of deception jamming simply need to match the signal strength of the radar return when it arrives at the victim radar, where it will be amplified by the radar as a valid return for processing and display. This requires less radiated power from the jammer. Effective deception jamming assumes that an effective technique is known and employed for a given threat radar.[44]

It should be noted that EA can only partially deny enemy SA. While jamming does degrade the enemy kill chain, the effects of EA are typically observable and will indicate the presence of fighters in the airspace. Noise jammers could "become a beacon, highlighting the aircraft when it would otherwise not have been detected."[45] This is especially true for low RCS fighters, which may prefer to avoid "own ship" emission and rely solely on LO to avoid detection. Deception jammers, however, are reactive. This means the threat radar has already detected, or is attempting to detect, the fighter before the jamming technique is utilized.[46] This makes deception jamming particularly useful for LO platforms, which can benefit greatly from EA. As indicated in figure 2, the benefits of EA are disproportionately higher for platforms with lower RCS.

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In those instances in which a fighters self protection jamming systems lack the complexity or power to defeat a threat, or when own ship emissions may compromise LO effects, the use of standoff jamming platforms may provide a solution. Standoff jammers, such as the US Navy's E/A-18G Growler, can utilize more advanced deception techniques and higher power levels. They can act as force multipliers, providing suppression for several fighters at once, and eliminate the risk of anti radiation weapons by staying beyond the range of the threat. They also eliminate the risk of highlighting a fighter which may otherwise remain undetected. The presence of EA that increases the noise threshold of potential threats makes the targeting of LO fighters even more difficult.

The F-35 design recognizes this benefit, and incorporates an electronic warfare suite into the aircrafts systems. The nature of the AESA radar also allows the radar aperture to be utilized as an electronic attack system.[47] This ability is inherent to the AESA, and any AESA radar could theoretically be employed as an electronic attack system.

Unlike LO, EA has little effect on the design of the airframe itself, and therefore imposes few limitations on the aircraft structure. As a result, EA is typically lighter, cheaper, and relatively easy to incorporate into a fighter's systems. Deception jammers are more complex, but typically smaller and lighter than noise jamming systems, making them ideal for fighter employment. These benefits have been realized and many fourth generation fighters incorporate deception jammers in the form of digitally repeated frequency modulation (DRFM) systems.[48]

A significant factor in lethality is weapons load out, or carriage capacity for air to air and air to ground weapons. It is pointless for a fighter to arrive in an offensive position of advantage if it does not carry the ordnance required to kill the intended target. While LO may enhance the fighter's ability to arrive at that position, it may also restrict the load out available to the fighter. This is because the carriage of external weapons that are non-stealthy will significantly increase the RCS of the fighter, as is illustrated by the upper end of the RCS range for the F-15 as listed in figure 3.

The CBO illustrates the impact of an all 5th generation fleet by comparing current capacity for air to air weapons with the expected capacity in 2035.

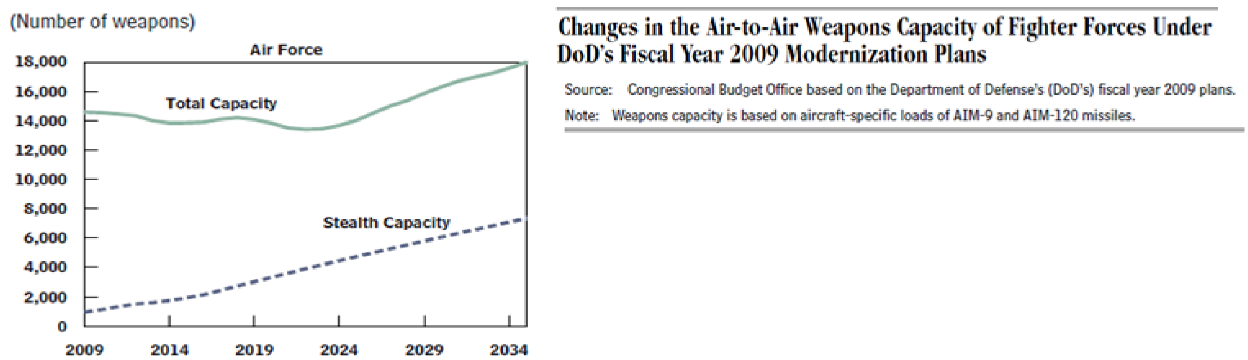

Figure 2: CBO Air to Air Weapons Capacity Over Time (Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces* [Washington DC: Government Printing Office, 2009], 22)

The data presented by the CBO includes all air to air missiles, as carried by all aircraft in service, and demonstrates a slight initial decrease in capacity followed by an increase in total capacity through 2036. This increase assumes external carriage by the F-35 and F-22.[49] As stated earlier, trends in air combat suggest that increased SA dictates that BVR missiles yield the best chances of surviving and winning the engagement.[50] For this reason, this study will primarily consider the carriage of AIM-120s, the current BVR missile in use. With the assumption that external tanks will be carried on all legacy or enhanced legacy fighters, and that the maximum carriage of AIM-120s will take priority over the possibility of loading the short range AIM-9, we see that the current capacity for BVR missiles is well below the predictions of the CBO:

Table 3. Current AIM-120 Capacity, Air to Air Loadouts

Type	Maximum # of AIM-120s	FTRs in Inventory	# OF AIM -120	notes
F-15C/E	8	468	3,744	2x External tanks
F-16C	4	1,017	4,068	2x External tanks
F-22	8	183	1,830	+ 2 aim 9 ea, external carry, 2x External tanks
	TOTAL:	**1,668**	**9,642**	F-22 carrying additional 366 AIM-9

Adapted from: Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces* (Washington DC: Government Printing Office, 2009) and United States Air Force. *USAF Fact Sheets.* 2015 http://www.af.mil/AboutUs/FactsSheets/tabid/131/Indextitle/F/Default.aspx (accessed Sept 23, 2015).

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As pointed out by the CBO, it is unlikely that LO fighters will utilize external carry when closing within engagement range of a BVR missile to a threat. Assuming internal carry only, the current USAF AMRAAMs capacity is 8,831 missiles. These numbers can be compared to the potential capacity in 2035:

Table 4: Predicted AIM-120 Capacity in 2035 for Air to Air Loadouts

Type	**Maximum # of AIM-120s**[51]	**FTRs in Inventory**[52]	**# OF AIM - 120**	**notes**
F-22	6	183	1,098	Internal carry
F-35A	4	1,763	7,052	Internal carry
F-22	8	183	1,464	External carry, 2x External tanks
F-35A	8	1,763	14,104	External carry, 2x External tanks
	TOTAL INTERNAL:	**1,946**	**8,150**	F-22 carrying additional 366 AIM-9 for either internal or external carry
	TOTAL EXTERNAL	**1,946**	**15,568**	

Adapted from: Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces (*Washington DC: Government Printing Office, 2009) and United States Air Force. *USAF Fact Sheets.* 2015 http://www.af.mil/AboutUs/FactsSheets/tabid/131/Indextitle/F/Default.aspx (accessed Sept 23, 2015).

Though external carriage of 5th generation fighters will more than double current capacity, internal carry restrictions will yield a decrease in the total BVR capacity of the USAF by approximately 8%.

A similar comparison is warranted for air to ground capacity. The CBO predicts an increase in capacity for both large, or 2000 lbs class weapons, and small, either 500 lbs class or Small Diameter Bomb (SDB), weapons to a combat radius of 600nm due to the F-35's improved combat radius and carriage over the F-16.[53] Capacity will decrease for all weapons, and most significantly the 2000 lbs class, beyond a range of 650 nm due to the combat radius and carriage of the F-15E that will retire over time. Based on the capacities listed below, a strike package of

including legacy aircraft may have a higher capacity than a 5th generation package in both carriage and range.

Table 5. Air To Ground Loadouts

FTR type	FTRS avail	2k lb load out	# OF 2k lb	500 lb load out	# of 500 lb	SDB load out	# of SDB	AIM-120 load out	# of AIM-120s	Combat Radius[note 1]
F-15E	40	5	200	13	520	20	800	4	160	1000
F-16C	40	2	80	6	240	12	480	2	80	400
F-22	40	0	0	2	80	8	320	2	80	600
F-35A	40	2	80	2	80	8	320	2	80	500
F-35 A external carry	40	4	160	6	240	16	640	4	160	600

Adapted From: Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces (*Washington DC: Government Printing Office, 2009), 17

Note 1: Ranges approximated, assumes at least 2x 2000lb weapons (except F-22)

In its analysis, the CBO makes very broad generalizations regarding weapons. For example, the capabilities and target sets for SDB are very different than many 500 lbs weapons, though the CBO suggests they are interchangeable. The CBO also did not account for weapons that will not fit into the bay of an LO platform. An example is the 19 foot, 5000 lb GBU-28, a Laser Guided Bomb (LGB) designed to penetrate extremely hardened bunkers with extreme accuracy.[54] Larger weapons can provide better standoff range, while external fuel tanks provide range and persistence or loiter time. External carry is a standard configuration for legacy fighters. While the external capacity of the F-35 narrows these differences considerably, the likelihood of it employing in a high threat environment in a non-LO configuration is low.

The cost of an airframe is vital to the discussion of the fighter gap. Increased costs and fiscal concerns have led to the issue. Higher costs of procurement and Operating and Sustainment (O/S) result in fewer aircraft purchased.

Table 6. Cost by Airframe

Airframe	F-15C	F-15E	F-16	F-22	F-35
2015 inventory	249	219	1017	183	-

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Cost per unit in millions	$29.9	$31.1	$18.8	$143.0	$106.7
O&S cost (fy2013)		$37,504	$22,954	$62,106	See Note 1

Adapted From: United States Air Force. *USAF Fact Sheets.* 2015
F-35 Cost Per Unit from: Jeremiah Gertler *Air Force F-35 Joint Strike Fighter (JSF) Program.* (Washington DC: Congressional Research Service, 2014) 16

Note 1: Estimates of annual O&S for the F-35A are not available. Annual O&S for the entire F-35 fleet is estimated at $18.2 for all variants, approximately 60% higher than the aircraft it will replace.[55]

This data highlights the trends that heavier and more complex airframes are more expensive to procure and operate. Fighters in general are growing in cost as reliance on software becomes more critical.[56] Legacy "low end" fighters represented 71% of the fighter inventory at 63% of the cost of an F-15C. Today, the F-35 is 75% the cost of an F-22, and will represent 90% of the inventory in 2035, which further demonstrates the relatively higher cost of our future fleet. The high cost of 5th generation fighters may also have an impact on the degree to which losses will be acceptable. Losing an aircraft may become an unacceptable potential when the cost of that fighter is three or four times that of a legacy fighter or represents such a large percentage of the total acquisition budget.

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The final criterion for evaluation is the relative need for 4th and 5th generation fighters based on the potential scenarios in which they will be employed. These potential scenarios fall on a spectrum ranging from low intensity conflict, such the CAS-centric Irregular Warfare experienced in Iraq and Afghanistan, to high intensity conflict with a near-peer adversary such as China. While the likelihood of these or other scenarios is a subject that requires further examination, this study assumes an equal potential for either scenario.

China is a near-peer adversary in that it currently boasts technological advancements and threat numbers that are nearly equal to that of the United States and are rapidly growing.[57] China is likely to employ long range Anti-Access/Area Denial (A2/AD) weapons, electronic attack,

advanced Surface to Air Missiles, and large quantities of fighters, to include the indigenous 5th generation fighter currently under development.[58] A key concern in this scenario is survivability. LO and EA will be necessary to counter advanced SAMs and fighters, and those aircraft that can effectively employ both will have an advantage. A2/AD capabilities will also drive the need for both standoff weapons and increased range and persistence, as “it is possible that existing fighter aircraft would have to refuel well inside of the range of China’s defenses, which may be able to reach and destroy aircraft at distances over 1,000 miles.”[59]

Force ratio will be an important factor in this scenario. Simulating an air to air scenario with a mixed force of F-22s and F-15Cs, Major Ronald Gilbert of the USAF demonstrated that an a notable increase in blue losses occurs when force ratios decline to less than 1 USAF fighter for every 2 adversaries, with a potential for total destruction of the USAF force.[60] Even with a ratio of 1:2, heavy losses occur, and a numerical advantage is required to minimize blue losses.[61] Smaller numbers of expensive fighters do not support the likelihood of numerical advantage.

While this simulation does not account for the potential of added survivability of an F-35, it does find that 5th generation survivability improves when integrated with sufficient numbers of legacy fighters, as “it becomes much more difficult to find a stealth aircraft when surrounded by more than twenty non-stealth platforms.”[62]

The force ratio considerations become even more significant when one considers the effect of EA on USAF fighter lethality. Gilbert states that China’s use of EA is expected to degrade BVR missile effectiveness by 40% or more.[63] The following chart depicts the impact on the number of missiles required to ensure destruction of air threats for given level of EA in Gilbert’s China scenario, in which a force of 200 initial adversaries is reinforced by an additional 100 enemy fighters:

AIM-120's required for no EA				
Single Missile Probability of Kill	Number of missiles per target	Probability of Killing the Target	Number of Aircraft to Kill	Number of Missiles Required
100.0%	1	100.00%	300	*300*
AIM-120's required 20% EA effectiveness				
Single Missile Probability of Kill	Number of missiles per target	Probability of Killing the Target	Number of Aircraft to Kill	Number of Missiles Required
80.0%	2	96.00%	300	*625*
AIM-120's required 40% EA effectiveness				
Single Missile Probability of Kill	Number of missiles per target	Probability of Killing the Target	Number of Aircraft to Kill	Number of Missiles Required
60.0%	4	97.44%	300	*1,232*
AIM-120's required 60% EA effectiveness				
Single Missile Probability of Kill	Number of missiles per target	Probability of Killing the Target	Number of Aircraft to Kill	Number of Missiles Required
40.0%	6	95.33%	300	*1,888*

Table 3. AIM-120s in an EA environment

AIM-120 probability of kill, or Missile Pk, is considered in this case to be 100% effective with no EA. This is a conservative assumption. EA that is 40% effective will yield an AIM-120 Pk of 60%. Probability of Kill refers to the likelihood that the number of shots shown will result in killing the intended target with the listed degree of certainty. A Probability of Kill over 95% was chosen for this study.

A comparison of the air to air load outs (figure 6) demonstrates that with 40% effective EA, and an expected fleet ratio of roughly 1 F-22 for every 10 F-35s, the minimum number of fighters required to defeat the Chinese fighters is 28 Raptors and 270 F-35s. This does not allow for any blue losses prior to expending all missiles, which is a likely outcome according to Gilbert's simulations. While this does result in 56 additional AIM-9s carried by the F-22s, attempting to employ these missiles within visual range (WVR) negates many of the survivability characteristics of the aircraft and will likely result in additional losses. The need for more missiles is more significant when fighters are operating with dual role or air to ground configurations for strike operations. The quantity of missiles required in an EA environment therefore requires large force ratios, and favor larger airframes with "a deep magazine of long-range air-to-air weapons,"[64] with robust sensors.

Unlike a near-peer scenario, the wars in Afghanistan and Iraq over the last decade have demonstrated that a lack of threats to air assets allows a variety of legacy platforms to operate with impunity in low intensity CAS scenarios. While survivability, with the exception of against small arms ground fire, is far less a factor, the primary threat is procurement or O/S costs that prevent sufficient numbers of fighters from being available in these scenarios. Lethality is a far more significant concern, with a need for both persistence a large number and variety of air to ground weapons. Persistence in this case is a factor of both range and loiter time.[65]

The final factor in considering the need for either 4th or 5th generation platforms is matter of contingencies. Two factors emerge when considering the benefits of a more uniform fleet versus a more diverse fighter fleet. The first is a matter of maintenance risk. A RAND Corporation study suggests "the Air Force needs to hedge against the possibility that an individual fleet may have a cost or availability surprise."[66] This is evident in the fleet wide grounding for the F-22 following several incidents of pilot hypoxia symptoms in 2010.[67] RAND suggests that procuring multiple airframe types provides this "hedge."[68] While a single platform fleet has a 2.2% chance of a fleet wide grounding based on historical data, a 2 platform fleet reduces that risk to just 0.05%.[69] A single platform also imposes a tactical risk, as a single platform provides less tactical flexibility and invokes difficulty in overcoming vulnerabilities.[70]

Evaluation

Now that the capabilities, cost, and need for both legacy and 5th generation platforms have been examined, the suitability of each airframe type can be evaluated based on these criteria. Lethality and survivability tend to favor 5th generation aircraft. While legacy and enhanced legacy fighters employ EA, 5th gen fighters have the option of employing EA more effectively in conjunction with their reduced RCS, which enhances their survivability over legacy platforms.

In order to improve lethality, enhanced legacy fighters are adopting AESA radars and upgrading sensors. 5th gen fighters have superior sensors, however, as they employ sensor fusion from a wider variety of sources. 5th generation fighters can improve their lethality by carrying external stores, but are unlikely to do so in a contested environment. This gives legacy fighters a slight advantage in both weapons carriage and range, as some legacy fighters (such as the F-15E) can carry larger payloads over greater distances. This advantage could be mitigated by 5th gen fighters carrying external stores, but the cost of a potential loss makes this course of action unlikely. Finally, aircraft performance is equal for the platforms. While the F-22 has far greater performance capabilities than legacy fighters, the modest capabilities of the F-35 indicate the passing, albeit relative, importance of aircraft performance.[71]

Cost is a factor that clearly favors the legacy and enhanced legacy fighters. Procurement costs are far higher for the LO platforms, and the current F-35 procurement cost was considered unaffordable by the 1992 procurement plan.[72] O/S costs are also much higher for the 5th generation platforms. The F-22 has demonstrated higher operating costs than even the larger and heavier F-15E, and concerns over estimated F-35 operating costs have led some defense officials to believe the platform's sustainment is unaffordable.[73]

The A2/AD challenges of a near peer scenario require "family of systems," utilizing stealth and standoff.[74] This combination of capabilities can be achieved by leveraging the strengths of both 5th generation and enhanced legacy fighters. The superior sensors of 5th generation fighters allow for better SA and targeting effectiveness, while their improved survivability preserves force ratios. 5th generation platforms are, however, limited by their smaller weapons carriage capacity and shorter range in near-peer scenarios Enhanced legacy fighters can maintain survivability in near-peer scenarios through the use of EA, standoff, and sound tactics. Their

added capacity for weapons carriage and range can enhance fleet lethality. Enhanced legacy fighters can help LO platforms avoid detection, while 5th generation fighters improve legacy fighter SA and targeting. These factors suggest that a near-peer scenario favors a combination of enhanced legacy and 5th generation fighters and the advantages they offer.

The capabilities required in a CAS scenario favor enhanced legacy fighters. The enhanced legacy fighter's greater range, persistence, and weapons carriage result in a greater suitability for irregular warfare scenarios. While a 5th generation fighter is capable in the CAS scenario, the procurement and operating cost, coupled with lesser loiter capability and weapons carriage, make them less desirable in a CAS environment.

Finally, an enhanced legacy addition to the fleet can act as a "hedge" against unforeseen maintenance and tactical vulnerabilities. A greater variety in platforms enables improved tactical flexibility and reduces the odds of severe maintenance and sustainability problems. This suggests a mixed force of 5th generation and enhanced legacy fighters is favorable.

With the understanding that the Air Force has demonstrated a preference for maximizing fighter capabilities over airframe quantities, and the fact that all of the alternatives result in additional financial burden, the CBO alternatives can be compared. Alternative 1 dictates accelerating the purchase of F-35s and increasing the total number bought by 164 aircraft. This plan will cost $5 billion more than the current procurement plan.[75] This alternative is flawed in that it would not only increase cost substantially, but would provide only a marginal increase in capacity. The capacity to deliver 2000 lbs weapons beyond 650nm would not be improved, persistence would not increase, and the concerns over O/S affordability would be amplified. Additionally, it would not alleviate the risk associated with maintenance or tactical vulnerabilities.

Before moving on to Alternative 2, Alternative 3 can be dismissed rather quickly. Alternative 3 calls for the purchase of 1,925 enhanced legacy fighters (F-16Es) and cancelling all F-35 purchases.[76] This alternative is infeasible due to the costs incurred for reimbursing international partners the costs of F-35 development,[77] and because the F-35 capabilities are demonstrably necessary in a near-peer threat environment. With smaller numbers of fighters overall, the survivability and lethality of the F-35 is required in addition to the F-22. Alternative 3 would leave the USAF less capable than current plans, particularly in terms of the survivability that LO platforms offer.

Alternative 2 involves purchasing 270 fewer F-35s, and buying 435 enhanced legacy fighters.[78] With Alternatives 1 and 3 dismissed, this alternative is the most suitable for bridging the fighter gap in terms of numbers of aircraft. Overall capabilities, however, do not significantly improve. This is due to the CBOs recommendation of the F-16E as the enhanced legacy fighter to be purchased. In terms of the capabilities examined in this study, a fighter such as the F-15SA would be a better choice, and would make alternative 2 the most suitable choice for closing the fighter gap in both terms of numbers and capabilities. This is evident in a comparison of the F-16E and F-15SA.

The F-16E is the latest export version of the F-16, and is in service in the United Arab Emirates. It features dorsal conformal fuel tanks that improve range, an APG-80 AESA radar, and improved thrust.[79] The F-15SA is an upgraded F-15E, currently being exported to Saudi Arabia. It features an APG-63 AESA radar, improved thrust, an upgraded electronic warfare suite, IRSTS, and a drastically increased air to air missile capacity.[80]

The limiting factor between the two airframes is cost, as is compared on the revised Table 6 below:

Table 8. Cost by Airframe with Enhanced Legacy Fighters

Airframe	F-15C	F-15E	F-16	F-22	F-35	F-15SA	F-16E/F
2015 inventory	249	219	1017	183	-	-	-
Cost per unit in millions	$29.9	$31.1	$18.8	$143.0	$106.7	$55.8	$48-50
O&S cost (fy2013)		$37,504	$22,954	$62,106	See Note 1	Not available	Not available

Adapted From: United States Air Force. *USAF Fact Sheets.* 2015
F-35 Cost Per Unit from: Jeremiah Gertler *Air Force F-35 Joint Strike Fighter (JSF) Program.* (Washington DC: Congressional Research Service, 2014) 16
F-16E Cost Per Unit Estimated by: Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces* (Washington DC: Government Printing Office, 2009), 46
F-15SA Cost Per Unit adapted from: Congressional Budget Office. *Balance and Affordability of the Fighter and Attack Aircraft Fleets of the Department of Defense.* (Washington DC: Government Printing Office, 1992) 25

Note 1: Estimates of annual O&S for the F-35A are not available. Annual O&S for the entire F-35 fleet is estimated at $18.2 for all variants, approximately 60% higher than the aircraft it will replace.[81]

The cost of the F-15SA is estimated based on the historical trend of an aircraft's cost increasing 80% from one generation to the next.[82] With this in mind, the CBO's estimate of the F-16E is 255% higher than the F-16C, partially due to Research and Development costs.[83] If the F-15SA procurement cost grew at the same rate, the cost would be approximately $79 million each. The USAF could elect to reduce its enhanced legacy purchase from the CBO proposal to 200 aircraft, roughly mirroring the current F-15E fleet as a medium attack aircraft, and reduce the overall cost. For the cost of 200 F-16Es, estimated to be $9.6 billion, the USAF could purchase 120 to 170 F-15SAs. Research and Development costs should be negligible for the F-15SA as they are already in production for the Saudi Air Force. While O/S costs are not available for these aircraft, a comparison of the F-16C and F-15E will likely provide some insight to the costs relative to one another. Historically, the O/S cost of 2 F-15E squadrons is equal to that of 3 F-16 squadrons.[84] According to a RAND Corporation study, the "effectiveness advantage offered by the F-15E relative to the F-16C was more than commensurate with its higher procurement and operating costs."[85] This is evident in the comparisons below:

Table 9. Comparison of Current AIM-120 Loadout with Enhanced Legacy Fighters

Type	Maximum # of AIM-120s	FTRs in Inventory	# OF AIM -120	notes
F-15C/E	8	468	3,744	2x External tanks
F-16C	4	1,017	4,068	2x External tanks
F-22	8	183	1,830	+ 2 AIM-9 ea, external carry, 2x External tanks
F-15SA	**12***	**120**	**1440**	**+ 4 additional AIM-9, *may allow 4 additional AIM-120 each, 2 x external tanks**
F-16E	**4**	**200**	**800**	**2x external tanks**

Adapted from: Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces (*Washington DC: Government Printing Office, 2009), 46 and United States Air Force. *USAF Fact Sheets.* 2015

While the F-16E's range improves to nearly match that of the F-15SA, the carriage capacity remains to fall short. Despite fewer numbers, F-15SAs produce an 80% increase in AIM-120s over the F-16E in an air to air configuration, and a 17% increase in the year 2035 total capacity when the 5th generation fighters employ internal carriage. Moreover, the range of the of the F-15SA's APG-63 exceeds that of the F-16E, providing enhanced SA.[86]

This difference becomes more profound in an air to ground role:

Table 10. Comparison of Enhanced Legacy Fighter Air to Ground Capacity

A/G LOADOUTS										
FTR type	**FTRS avail**	**2k lb load out**	**# OF 2k lb**	**500 lb load out**	**# of 500 lb**	**SDB load out**	**# of SDB**	**AIM-120 load out**	**# of AIM-120s**	**Combat Radius (estimated)**
F-15SA	120	5	600	13	1560	28	3360	8	960	1000
F-16E/F	200	2	400	6	1200	12	2400	2	400	700

Adapted from: Congressional Budget Office, *Alternatives for Modernizing U.S. Fighter Forces (*Washington DC: Government Printing Office, 2009)

As shown in Table 10, the F-15SA more than doubles the carriage capacity of the F-16E in every category. Despite the fewer numbers of aircraft, the F-15SA has the potential to improve the total fleet capacity for 500 lb weapons by 40% when compared to 5th generation fighters with internal carry. More importantly, it provides significantly more capacity for 2000 lb weapons beyond 600nm. For an Air Force that demands capacity over quantity, the F-15SA is the more capable choice. Finally, with Lockheed Martin fully committed to the production of F-35s, the company's ability to produce F-16Es is likely limited.[87]

Recommendations

In accordance with the CBO's Alternative 2, the USAF should purchase a platform such as the F-15SA in order to fill the fighter gap. Approximately 200 aircraft would minimize overall investment while providing significant impact in fighter weapons capacity, and should be considered a minimum procurement goal. While procurement in higher numbers, such as the 435 proposed by the CBO, will yield a larger increase in force capacity, it will certainly result in fewer F-35 purchases based on budget limitations. The deferment or reduction of F-35 procurement will, at some point, have a diminishing return in cost savings. The F-35 provides significant war fighting capability, and reductions should only occur as financial restraints demand. The exact number of F-35 and enhanced legacy fighters purchased will be determined by the actual costs of enhanced legacy fighter production once a contract has been negotiated, and is likely to change as production of each continues.

Though the F-16E may be the most affordable enhanced legacy fighter by strict dollar value, the limitations inherent in its design offer a marginal return on that investment. More specific estimates of the actual procurement and sustainment costs of the F-15SA are required, and study should also be done to examine alternative platforms that may provide similar capability enhancement at a lower cost. One potential aircraft is the USN's F/A-18E/F. This may reduce initial investment, as the aircraft is already in use by the USN, but would not mitigate the risk of maintenance or tactical vulnerabilities as a distinct airframe would.

Further investment and study is required to enhance the capabilities of our BVR missiles. Limited kinematics and reduced Pk in EA environments limits effectiveness. Gilbert recommended developing missiles that match AIM-120 kinematics in a smaller missile bodies in order to maximize internal carriage.[88] Perhaps an easier technological feat is to provide better

kinematics in a larger body. This may allow employment from external carriage utilizing standoff ranges beyond threat engagement envelopes. Such a development would increase the effectiveness of both enhanced legacy fighters and LO platforms.

Conclusion

Given the potential value added to the USAF by an enhanced legacy fighter, the CBO's Alternative 2 would be the most suitable choice for closing the fighter gap. 5th generation fighters exhibit capabilities that are revolutionary and have the advantage in survivability and situational awareness due to their sensors. Enhanced legacy fighters such as the F-15SA have an advantage in range, persistence, weapons carriage, and cost. The potential for near-peer adversaries and maintenance or tactical vulnerabilities illustrate the need for both 5th generation and enhanced legacy fighters. When integrated with 5th generation platforms, enhanced legacy fighters are the best "capabilities bridge" between the aging legacy fighters and the future replacements to the F-22 and F-35. While the nature of air warfare is unclear beyond 2035, it is clear the fighter aircraft will continue to dominate the sky for the next 20 years.

Notes

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